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(54) **METHOD FOR MATCHING TIMING ON
HIGH FANOUT SIGNAL PATHS USING
ROUTING GUIDES**

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(52) **U.S. Cl.** **716/126; 716/129; 716/130**

(58) **Field of Classification Search** **716/12-15,**
716/126, 129, 130, 134
See application file for complete search history.

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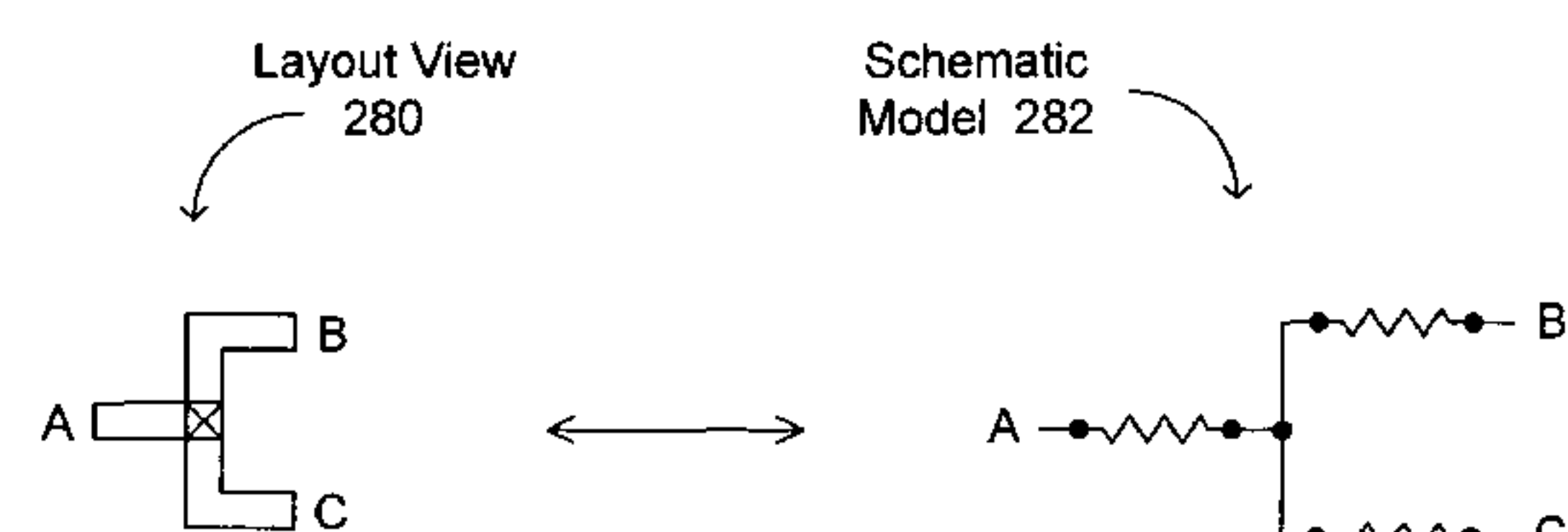
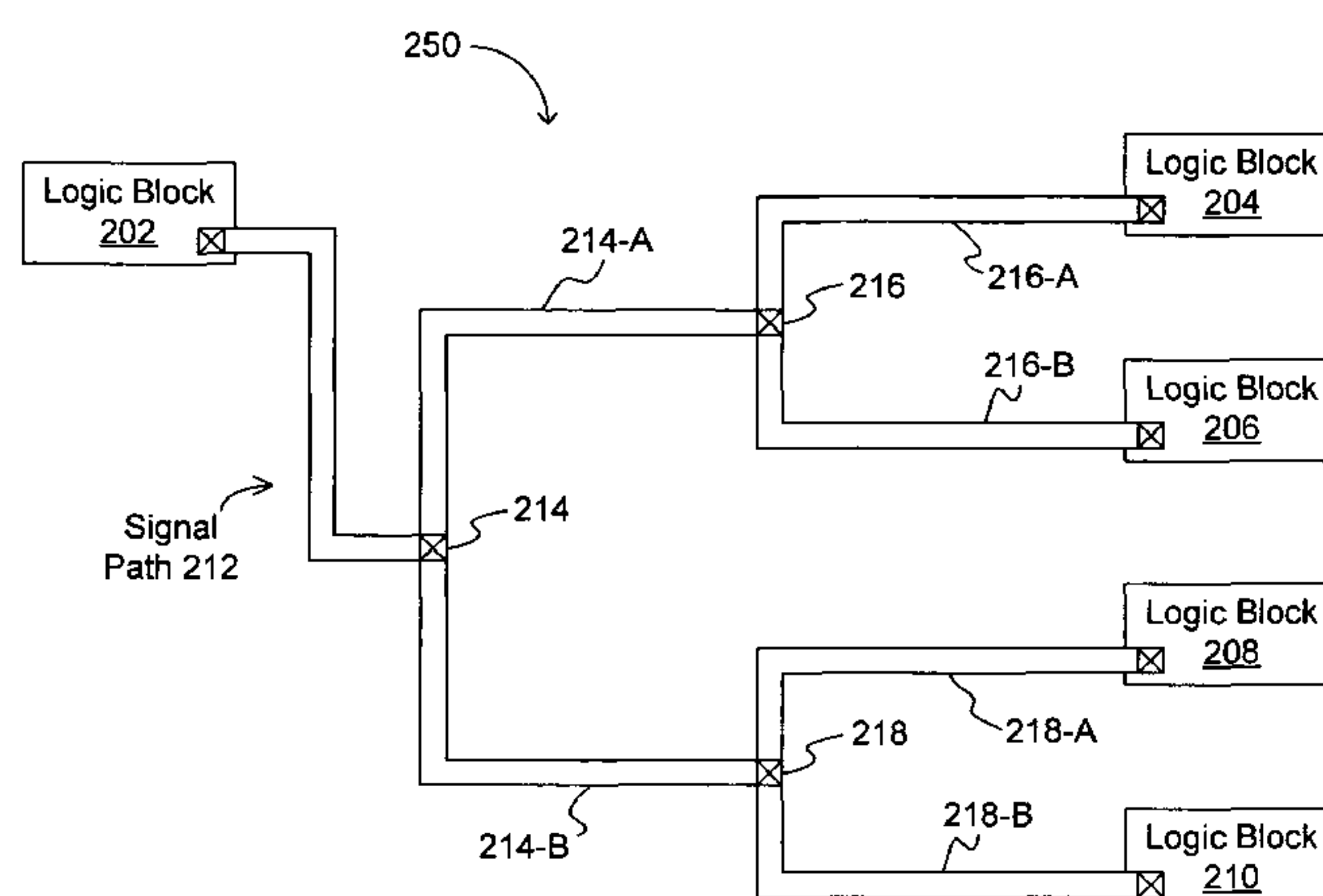
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(57) **ABSTRACT**

A method, algorithm, software, architecture and/or system for routing signal paths or connections between circuit blocks in a circuit design is disclosed. In one embodiment, a method of routing can include: (i) determining a signal path between at least three circuit blocks; (ii) placing a routing guide; and (iii) routing the signal path through the routing guide such that a timing of a signal along the signal path at two or more the circuit blocks is substantially matched. The circuit blocks can include standard cells configured to implement a logic or timing function, other components, and/or integrated circuits, for example. The routing guide can include a splitter configured to branch the signal path into at least two associated segments. Embodiments of the present invention can advantageously improve signal timing for high fanout signal paths between circuit blocks in an automated place-and-route flow.

51 Claims, 5 Drawing Sheets



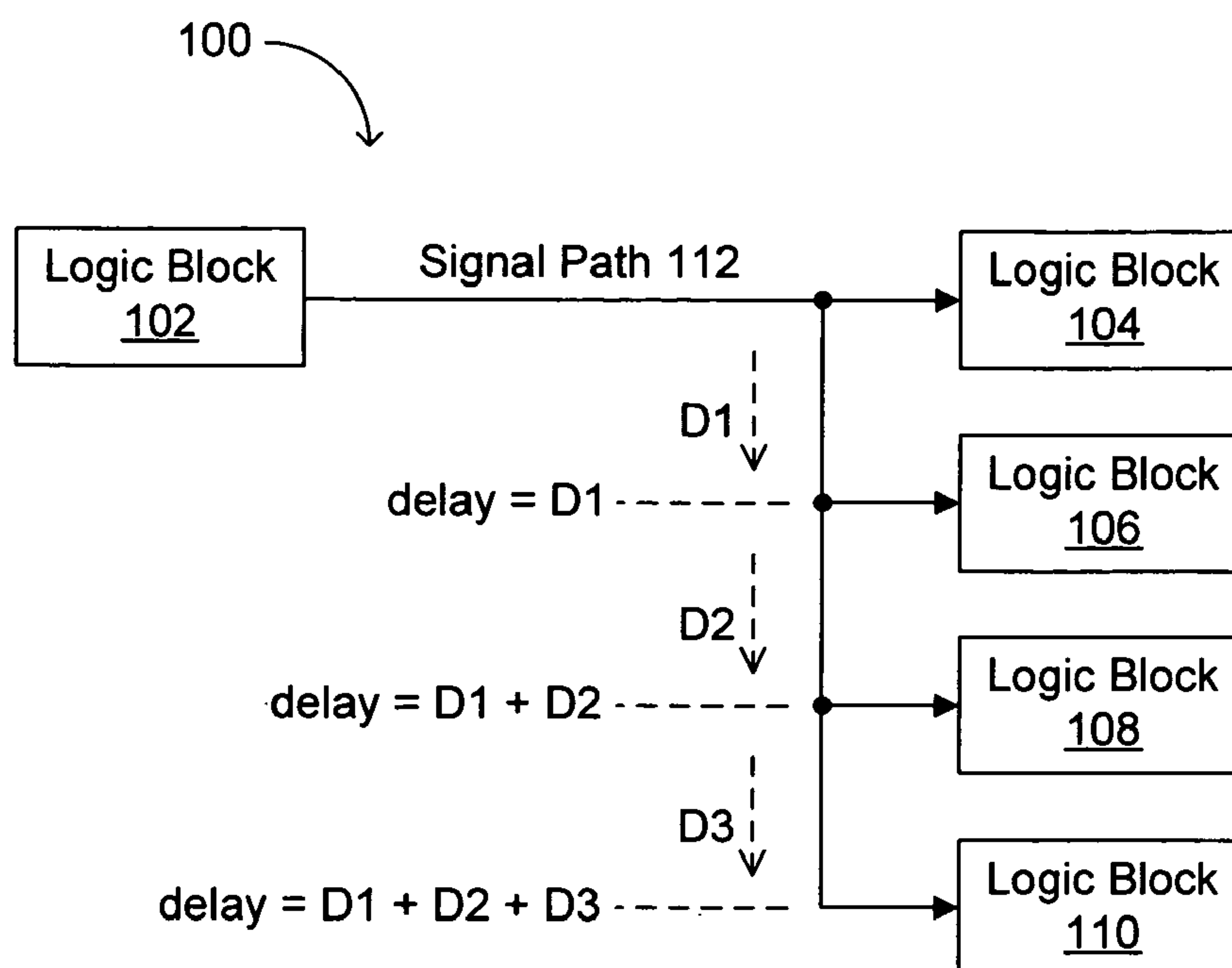


FIG. 1 (conventional)

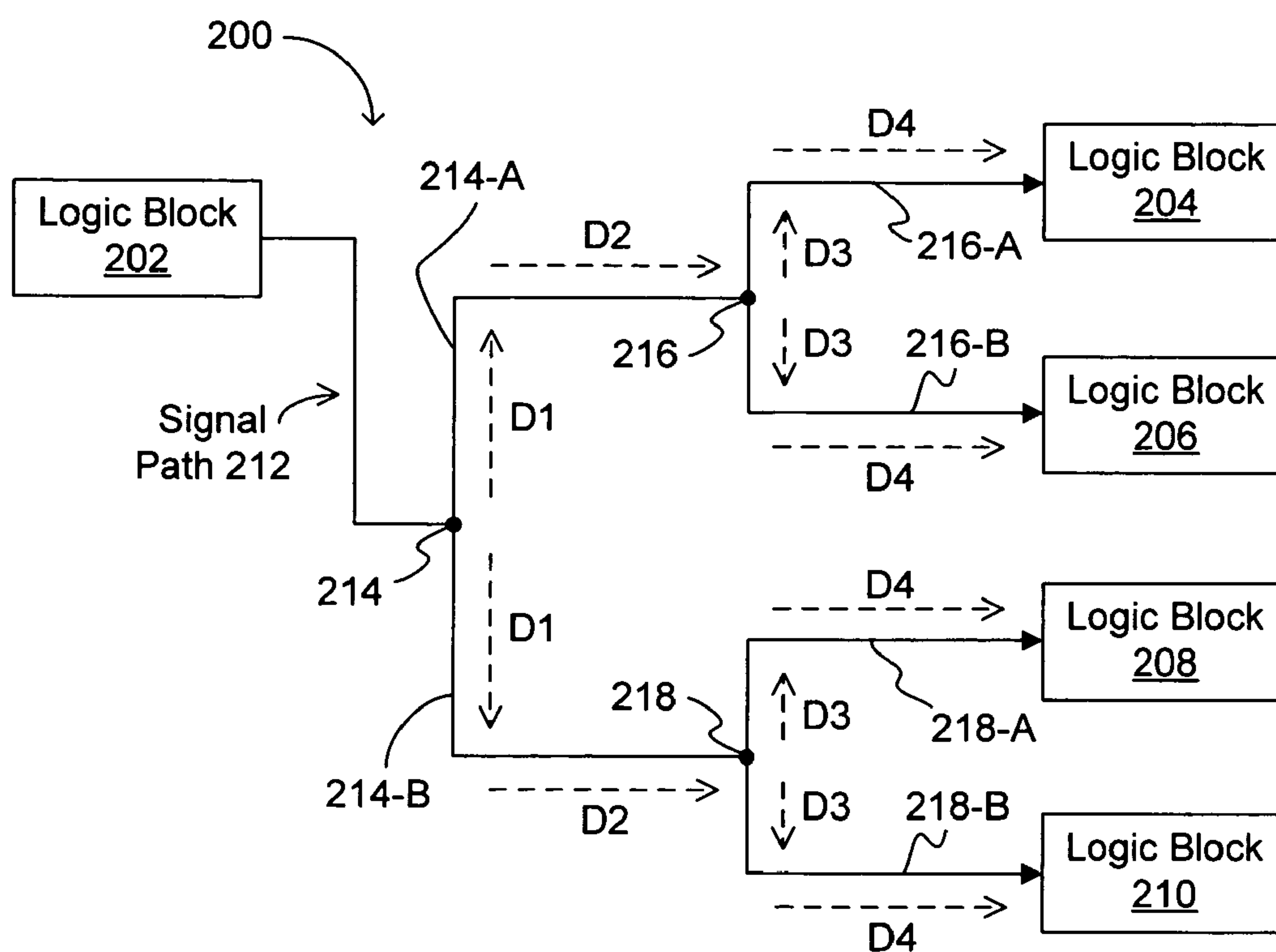
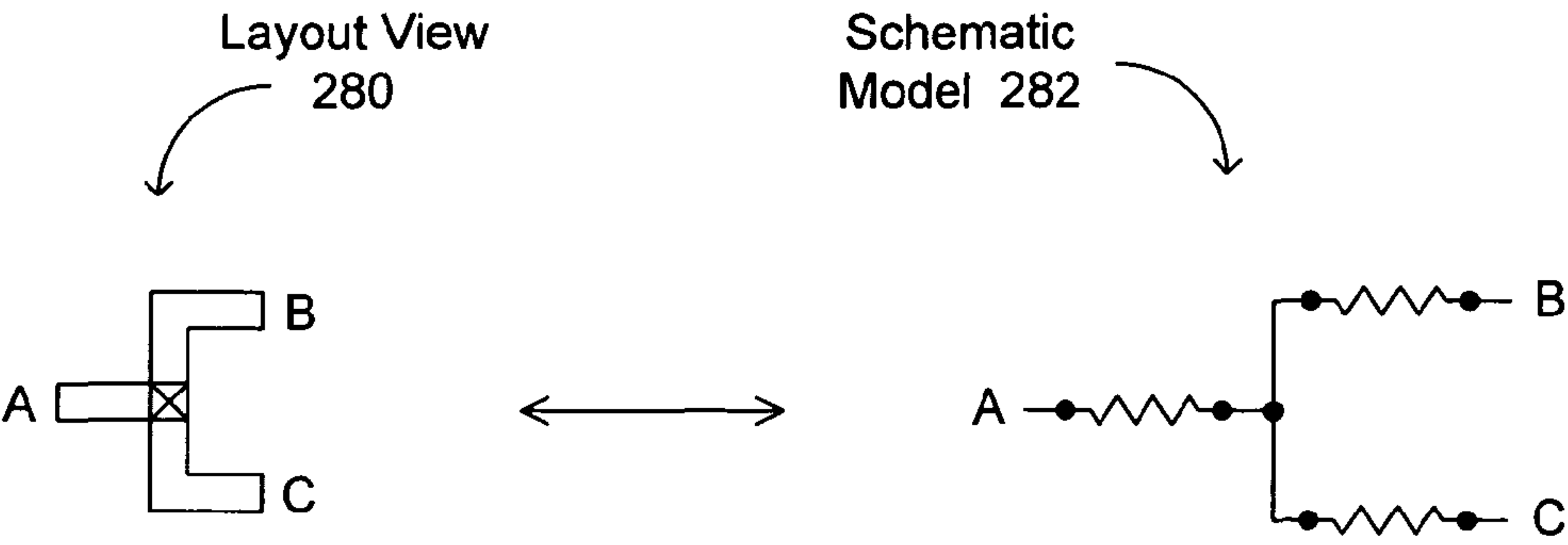
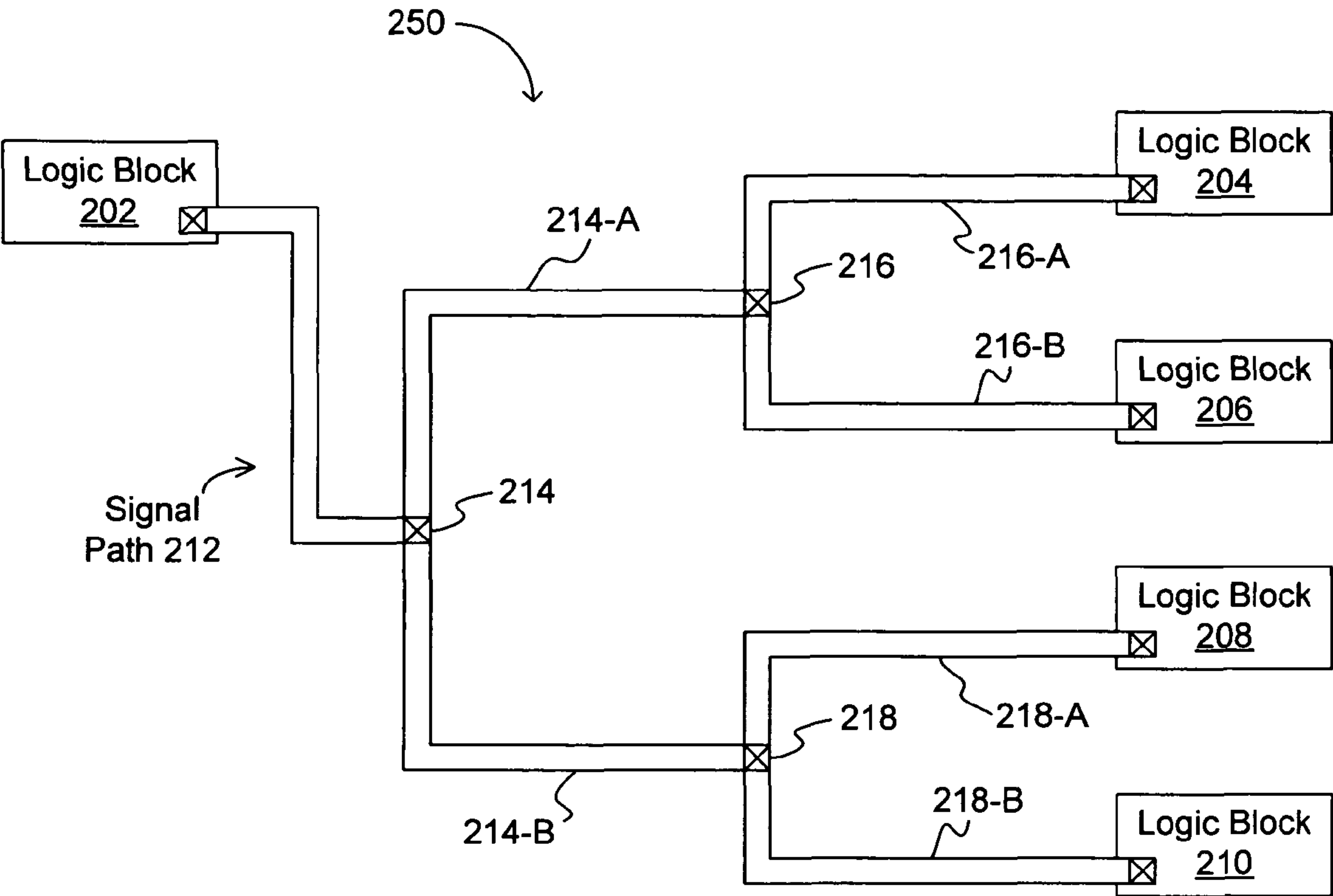


FIG. 2A



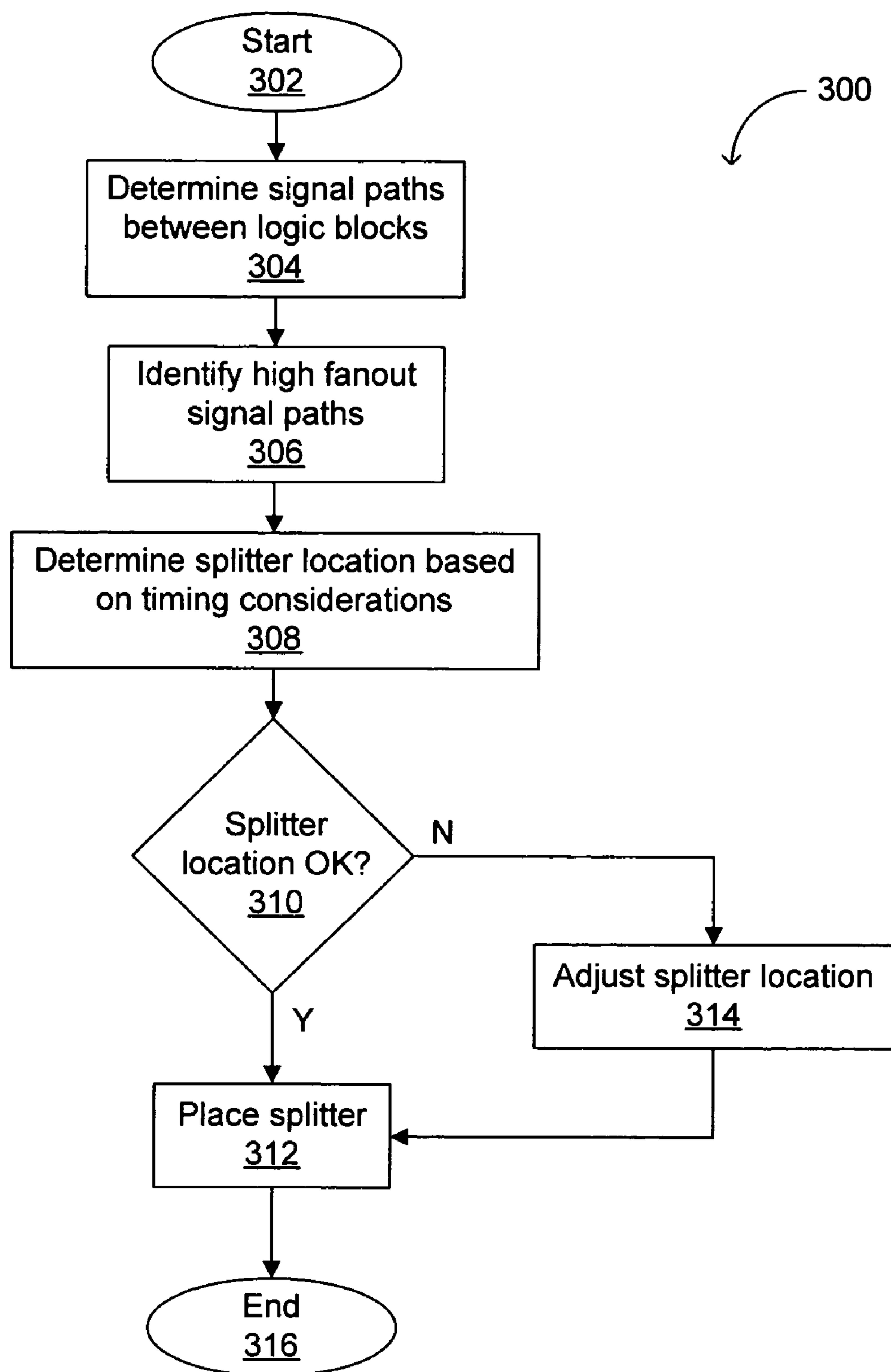


FIG. 3

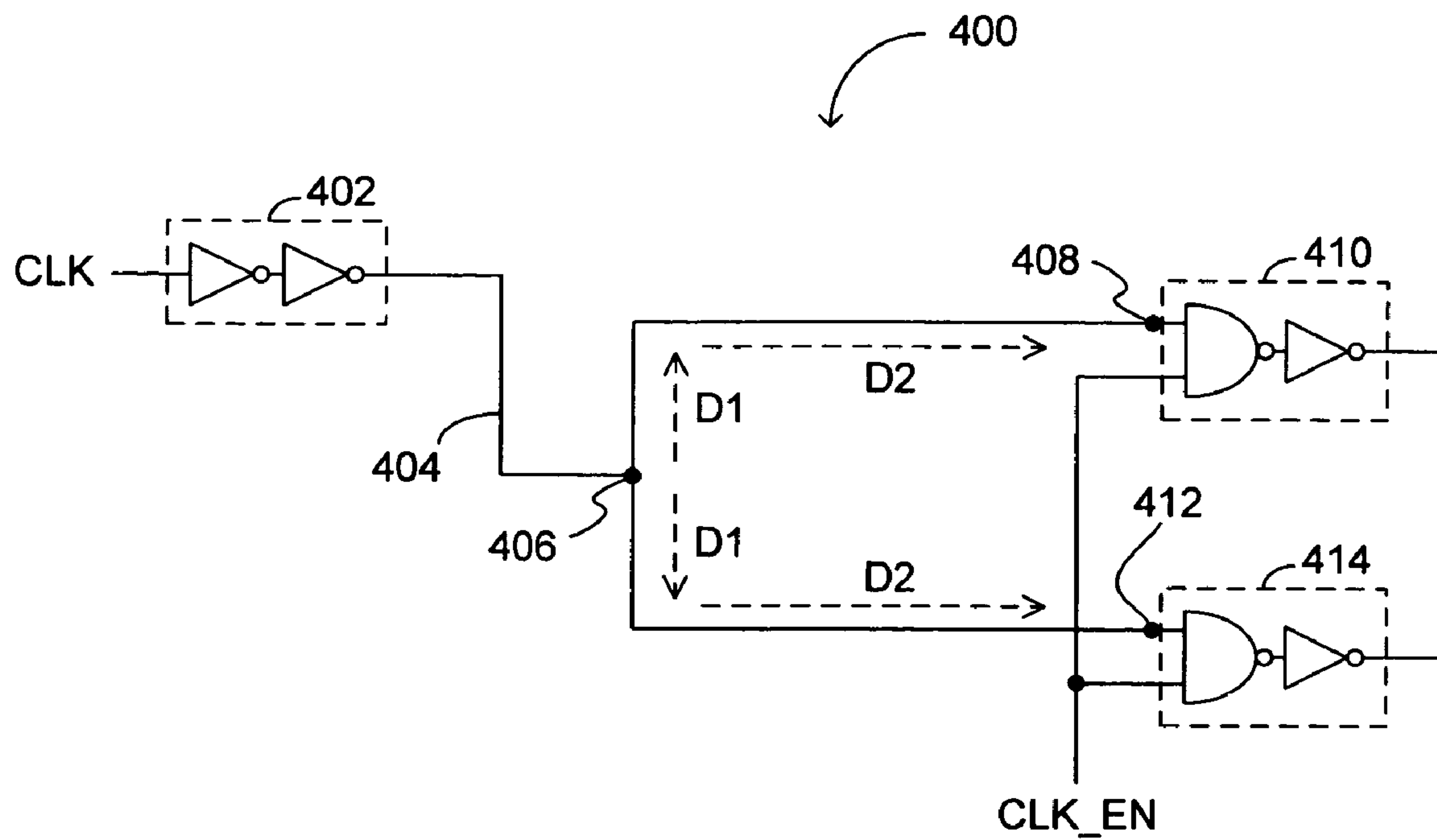


FIG. 4A

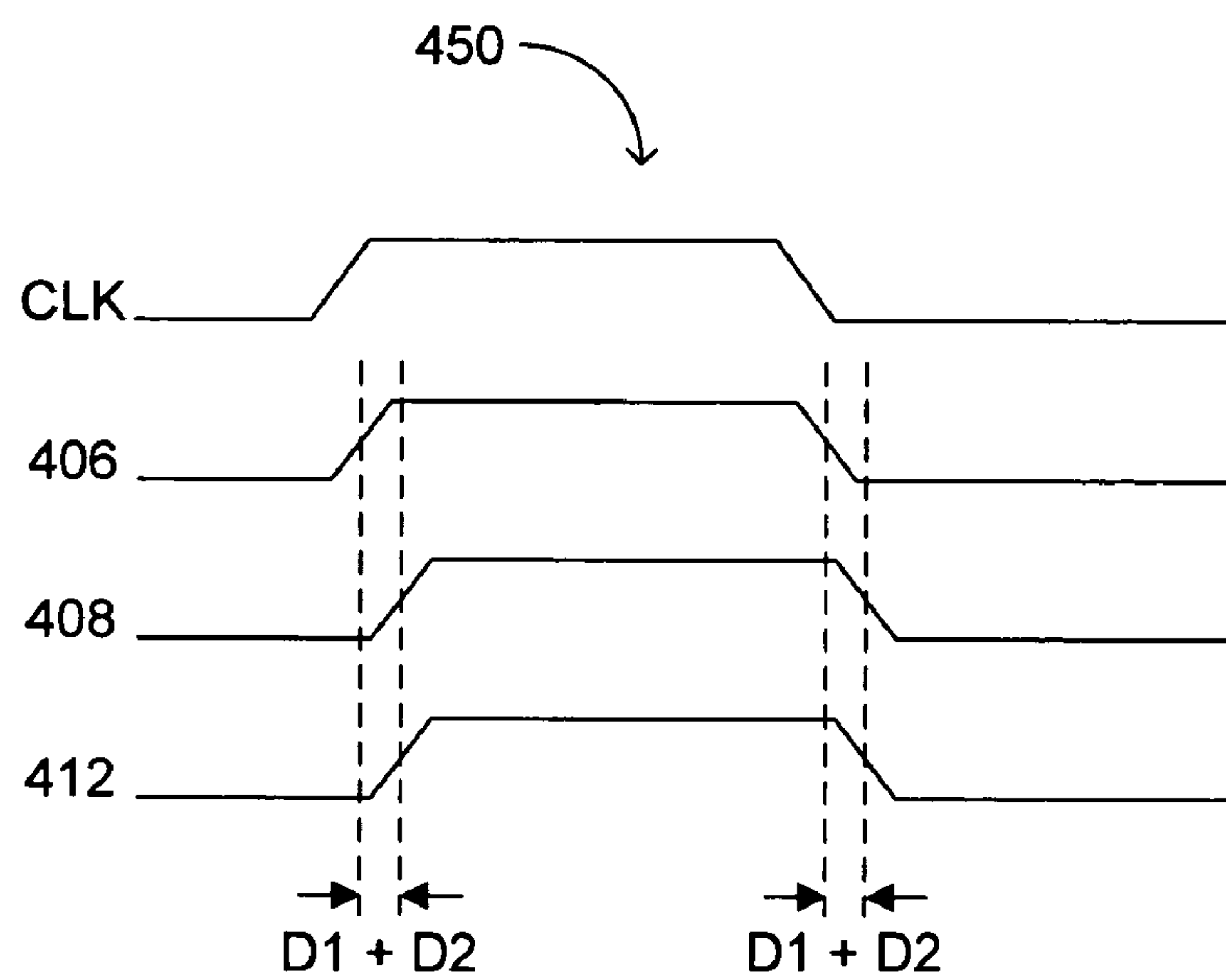


FIG. 4B

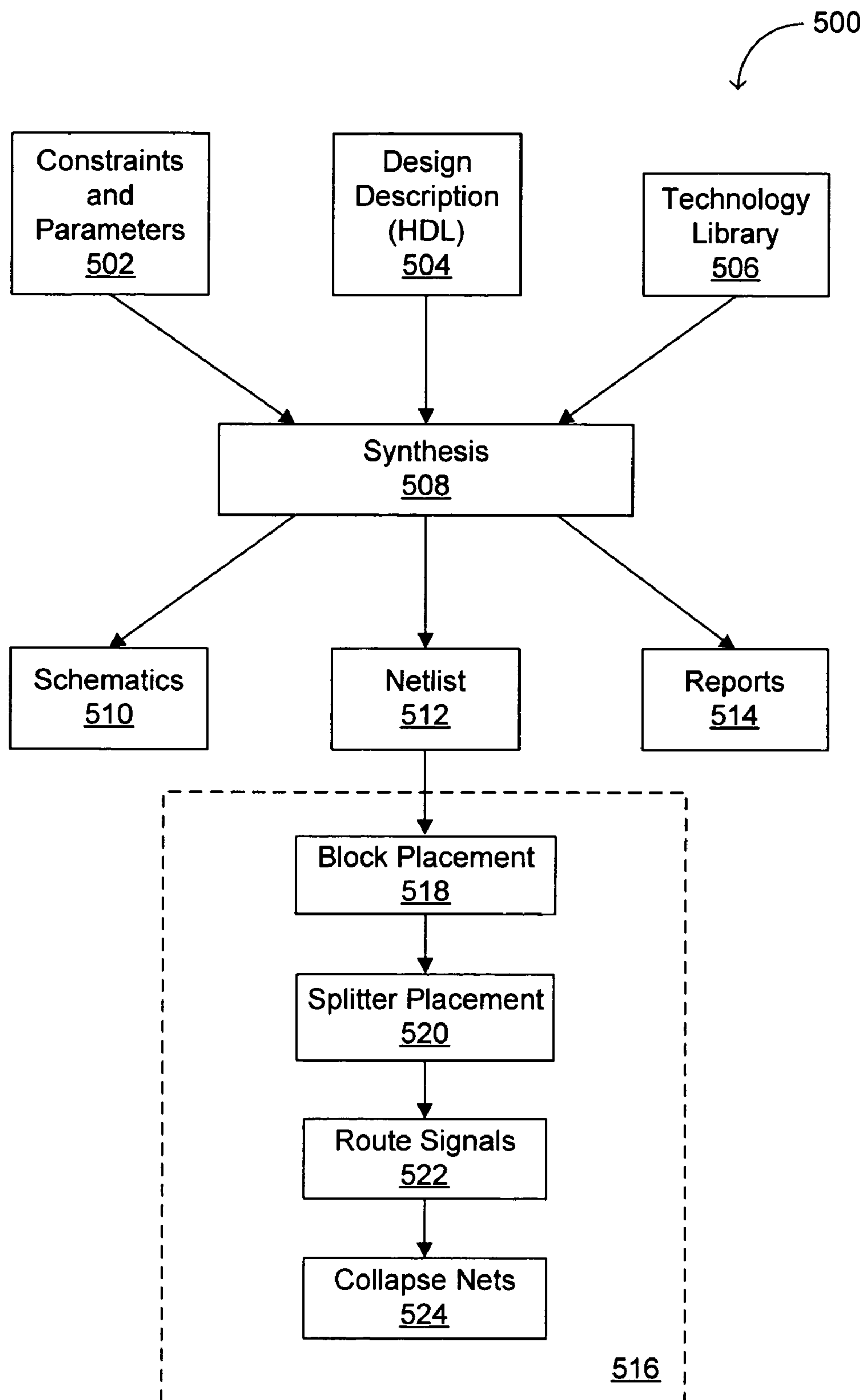


FIG. 5

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METHOD FOR MATCHING TIMING ON HIGH FANOUT SIGNAL PATHS USING ROUTING GUIDES

FIELD OF THE INVENTION

The present invention generally relates to the field of circuit design, particularly integrated circuit (IC) design. More specifically, embodiments of the present invention pertain to methods, algorithms, software, systems and architectures for improving signal timing in the design of an IC.

DISCUSSION OF THE BACKGROUND

In typical circuit design, circuit components are arranged to optimize space and/or circuit performance. Such arrangements can include the "layout" or pattern definition of each of the layers used in a semiconductor manufacturing process. For example, such layout can include metal interconnect or connectivity layers that are converted to masks or reticles for use in a wafer fabrication facility that manufactures ICs (i.e., "chips").

While some circuits are designed using "custom" layout, others are designed using a partially or fully automated design flow. Application-Specific Integrated Circuit (ASIC) designs, as well as other functional blocks within a larger chip, such as System-On-Chip (SOC) designs, may employ custom and/or ASIC type flows on the same chip. In any event, typical ASIC flows use "place-and-route" tools for placing logic or circuit "blocks" and then "routing" or connecting the interface signals between the blocks. Such routing between circuit blocks is typically done using one or more metal connectivity layers.

Referring now to FIG. 1, a box diagram showing a conventional routing for a high fanout signal path is indicated by the general reference character 100. Logic Block 102 is connected to Logic Blocks 104, 106, 108, and 110 via signal path 112. Such a multiple load and/or connection signal path may be considered a "high fanout" signal path for automated routing purposes. As shown, timing delays due to unmatched signal path routing can result in a delay D1 between Logic Blocks 104 and 106, a delay D1+D2 between Logic Blocks 104 and 108, and a delay D1+D2+D3 between Logic Blocks 104 and 110. Among the conventional approaches to address this timing disparity are: (i) the insertion of buffer stages; (ii) custom-routing high fanout signals; and/or (iii) adjusting block placements in order to obtain more favorable signal routing.

However, such conventional approaches to high fanout signal path routing are not desirable in an automated place-and-route flow. Inserting extra buffer stages merely for signal path routing facilitation takes chip layout area away from other functional circuit blocks and may increase a signal delay. Custom-routing high fanout signals can be a time consuming process that essentially defeats at least part of the purpose of an automated place-and-route flow. Similarly, adjusting block placements in order to assist high fanout signal routing may also be a time consuming process that does not effectively comport with an automated flow. Accordingly, signal path routing using conventional approaches may not improve high fanout signal path timing characteristics in an efficient manner.

Given the increasing demands on circuit designers to create chips of increasing density, decreasing wire and transistor widths, and decreasing power supply and power consumption, it is difficult to ensure optimal high fanout signal path timing in an automated place-and-route flow. Increasing the

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complexity, flexibility and/or functionality of the circuitry on a chip exacerbates these challenges. Thus, what is needed is a tool with which integrated circuit designers can efficiently optimize high fanout signal path routing and/or timing in an automated place-and-route flow.

SUMMARY OF THE INVENTION

Embodiments of the present invention relate to methods, algorithms, software, architectures and/or systems for routing signals or wires between circuit blocks in a circuit design.

In one embodiment, a method of routing can include: (i) determining a signal path between at least three circuit blocks; (ii) placing a routing guide; and (iii) routing the signal path through the routing guide such that a timing of a signal along the signal path at two or more of the circuit blocks is substantially matched. The circuit blocks can include standard cells configured to implement a logic or timing function, other components, and/or integrated circuits, for example. The routing guide can include a splitter configured to branch the signal path into at least two associated segments.

Embodiments of the present invention can advantageously improve signal timing for high fanout signal paths between circuit blocks in an automated place-and-route flow. Embodiments of the present invention are suitable for the automated routing of signal paths between circuit blocks within an integrated circuit (IC) and/or routing between ICs or components on a board, such as a printed circuit board (PCB).

These and other advantages of the present invention will become readily apparent from the detailed description of preferred embodiments below.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a box diagram showing a conventional routing for a high fanout signal path.

FIG. 2A is a box diagram showing a high fanout signal path routing according to an embodiment of the present invention.

FIG. 2B is a box diagram showing a simplified layout view of the signal path routing for the circuit of FIG. 2A resulting from the use of embodiments of the present invention.

FIG. 2C is a diagram showing layout and schematic views of a routing guide according to an embodiment of the present invention.

FIG. 3 is a flow diagram showing a routing guide placement method according to an embodiment of the present invention.

FIG. 4A is a schematic diagram showing an exemplary circuit that may be used to demonstrate the present invention.

FIG. 4B is an exemplary timing diagram for the circuit of FIG. 4A.

FIG. 5 is a box diagram showing a synthesis flow adapted for use with embodiments of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Reference will now be made in detail to the preferred embodiments of the invention, examples of which are illustrated in the accompanying drawings. While the invention will be described in conjunction with the preferred embodiments, it will be understood that they are not intended to limit the invention to these embodiments. On the contrary, the invention is intended to cover alternatives, modifications and equivalents, which may be included within the spirit and scope of the invention as defined by the appended claims. Furthermore, in the following detailed description of the

present invention, numerous specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be readily apparent to one skilled in the art that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, components, and circuits have not been described in detail so as not to unnecessarily obscure aspects of the present invention.

Some portions of the detailed descriptions which follow are presented in terms of processes, procedures, logic blocks, functional blocks, processing, and other symbolic representations of operations on code, data bits, data streams or waveforms within a computer, processor, controller and/or memory. These descriptions and representations are generally used by those skilled in the data processing arts to effectively convey the substance of their work to others skilled in the art. A process, procedure, logic block, function, process, etc., is herein, and is generally, considered to be a self-consistent sequence of steps or instructions leading to a desired and/or expected result. The steps generally include physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical, magnetic, optical, or quantum signals capable of being stored, transferred, combined, compared, and otherwise manipulated in a computer or data processing system. It has proven convenient at times, principally for reasons of common usage, to refer to these signals as bits, waves, waveforms, streams, values, elements, symbols, characters, terms, numbers, or the like, and to their representations in computer programs or software as code (which may be object code, source code or binary code).

It should be borne in mind, however, that all of these and similar terms are associated with the appropriate physical quantities and/or signals, and are merely convenient labels applied to these quantities and/or signals. Unless specifically stated otherwise and/or as is apparent from the following discussions, it is appreciated that throughout the present application, discussions utilizing terms such as “processing,” “operating,” “computing,” “calculating,” “determining,” “manipulating,” “transforming,” “displaying” or the like, refer to the action and processes of a computer or data processing system, or similar processing device (e.g., an electrical, optical, or quantum computing or processing device), that manipulates and transforms data represented as physical (e.g., electronic) quantities. The terms refer to actions and processes of the processing devices that manipulate or transform physical quantities within the component(s) of a system or architecture (e.g., registers, memories, other such information storage, transmission or display devices, etc.) into other data similarly represented as physical quantities within other components of the same or a different system or architecture.

Furthermore, in the context of this application, the terms “net list” (or “netlist”) and “hardware description” may be used interchangeably to refer to a circuit design represented in an appropriate language, such as VERILOG simulation language, Hardware Description Language (HDL) or VERILOG HDL (VHDL; VERILOG is a registered trademark of Gateway Design Automation Corporation for computer aided electrical engineering programs). Similarly, the terms “wire,” “wiring,” “line,” “signal,” “conductor” and “bus” refer to any known structure, construction, arrangement, technique, method and/or process for physically transferring a signal from one point in a circuit to another. Also, unless indicated otherwise from the context of its use herein, the terms “known,” “fixed,” “given,” “certain” and “predetermined” generally refer to a value, quantity, parameter, constraint, condition, state, process, procedure, method, practice, or

combination thereof that is, in theory, variable, but is typically set in advance and not varied thereafter when in use.

Similarly, for convenience and simplicity, the terms “clock,” “time,” “timing,” “rate,” “period” and “frequency” are, in general, interchangeable and may be used interchangeably herein, but are generally given their art-recognized meanings. Also, for convenience and simplicity, the terms “data,” “data stream,” “waveform” and “information” may be used interchangeably, as may (a) the terms “flip-flop,” “latch” and “register,” and (b) the terms “connected to,” “coupled with,” “coupled to,” and “in communication with,” but these terms are generally given their art-recognized meanings herein.

The present invention concerns a method and/or algorithm (e.g., a computer-readable set of instructions) for routing signal paths or connections between circuit blocks, and can include: (i) determining a signal path between at least three circuit blocks; (ii) placing a routing guide; and (iii) routing the signal path through the routing guide such that a timing of a signal along the signal path at two or more of the circuit blocks is substantially matched. The circuit blocks can include standard cells configured to implement a logic or timing function, other components, and/or integrated circuits, for example. The routing guide can include a splitter configured to branch the signal path into at least two associated segments.

In a further aspect of the invention, software relates to a medium or waveform containing a computer-readable set of instructions, where the instructions can be adapted to perform a method including: (i) determining a signal path between at least three circuit blocks; (ii) placing a routing guide; and (iii) routing the signal path through the routing guide such that a timing of a signal along the signal path at two or more of the circuit blocks is substantially matched.

In another aspect of the invention, a method and/or algorithm of connecting can include: (i) determining a plurality of signal paths interfacing circuit blocks; (ii) determining whether any of the plurality of signal paths are high fanout signal paths; (iii) placing a routing guide for an identified high fanout signal path; and (iv) routing the identified high fanout signal path through the routing guide such that a timing of a signal along the signal path at two or more of the circuit blocks is substantially matched.

In another aspect of the invention, a connection of circuit blocks can include: (i) at least first, second and third circuit blocks; (ii) a routing guide; and (iii) a signal path having at least first, second and third segments having first terminals respectively coupled to the first, second and third circuit blocks and second terminals coupled to the routing guide, such that a timing of a signal along first and second segments of the signal path substantially matches the timing of the signal along first and third segments of the signal path.

Embodiments of the present invention can advantageously improve signal timing for high fanout signal paths between circuit blocks in an automated or semi-automated place-and-route flow. Embodiments of the present invention are suitable for the automated routing of signal paths between circuit blocks within an integrated circuit (IC) and/or routing between ICs or components on a board, such as a printed circuit board (PCB).

The invention further relates to hardware and/or software implementations of the present architecture, method and system. The invention, in its various aspects, will be explained in greater detail below with regard to exemplary embodiments.

Referring now to FIG. 2A, a box diagram showing a high fanout signal path routing according to an embodiment of the present invention is indicated by the general reference char-

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acter **200**. Logic Block **202** can interface to Logic Blocks **204**, **206**, **208**, and **210** via signal or “signal path” **212**. Signal path **212** can include routing guides **214**, **216**, and **218**, as well as segments **214-A**, **214-B**, **216-A**, **216-B**, **218-A**, and **218-B**. A “routing guide” can be any marker or indicator other than a circuit block port or routing termination point that is used to guide the physical routing of a signal path. For example, a routing guide can be a splitter configured to branch the signal path into at least two associated segments (e.g., segments **216-A** and **216-B** may be “associated” with routing guide **216**) or a delay indicator configured to add delay or signal path length to the routed signal. Such additional signal path delay and/or length for a delay indicator may include sufficient signal path routing length so as to substantially match a signal path delay in another signal path, for example. Routing guide **214** is a splitter type so that signal path **212** can be segmented into two segments **214-A** and **214-B**, as shown. Further, such segments can each include two terminals. For example, segment **214-A** can include a terminal at splitter **214** and another terminal at splitter **216**. Splitter **216** can also be used to segment signal path **212** further for connections to Logic Blocks **204** and **206** by way of segments **216-A** and **216-B**, respectively. Similarly, splitter **218** can be used to segment signal path **212** further for connections to Logic Blocks **208** and **210** by way of segments **218-A** and **218-B**, respectively, as shown. Due to the use of splitters **214**, **216**, and **218**, each of Logic Blocks **204**, **206**, **208**, and **210** can see a substantially matched timing delay of $D1+D2+D3+D4$, as indicated.

Once the routing of signal path **212** is completed (e.g., in an automated routing flow), splitters **214**, **216**, and **218** can be removed. As such, routing guides can be “sacrificial” structures. Accordingly, any suitable marker or indicator can be used. Other examples of routing guides include any designated sacrificial circuit or element having at least one input and one output (e.g., a delay indicator), a similar structure having one input and two or more outputs (e.g., a splitter), or vice versa. Because the routing guides can be removed after the signal path routing, any conceivable structure configured to guide the routing of a signal path can be used as a routing guide.

In this fashion, a signal path can be routed between circuit or logic blocks, or other routing termination points (e.g., ports or other designations for subsequent signal connections, as in hierarchical layout block arrangements), through a routing guide, such as a splitter. Accordingly, such routing guides can be used to substantially match or otherwise affect the timing of high fanout signals, as measured at a plurality of the circuit block connections. Also, a particularly advantageous application for embodiments of the present invention involves routing clock signals or other signals having a high number of connection points.

Referring now to FIG. 2B, a box diagram showing a simplified layout view of the signal path routing for the circuit of FIG. 2A resulting from the use of embodiments of the present invention is indicated by the general reference character **250**. Signal path **212** may be routed in a particular connectivity layer, such as metal-2 (M2) or metal-3 (M3), or a combination of several layers. Splitter **214** may have a physical layout representation, such as a via layer (e.g., via-2 (V2)) or a designated unused layer (i.e., a layer not necessarily corresponding to or used in a wafer processing step). As shown, the routing for signal path **212** from Logic Block **202** may be split or may “branch” into two segments (e.g., segments **214-A** and **214-B**) by splitter **214**. Further, such segments can each include two terminals. For example, segment **214-A** can include a terminal at splitter **214** and another terminal at

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splitter **216**. The routing for signal path **212** may be further split into segments **216-A** and **216-B** by splitter **216** for connections to Logic Blocks **204** and **206**, respectively. Similarly, routing for signal path **212** may be split into segments **218-A** and **218-B** by splitter **218** for connections to Logic Blocks **208** and **210**, respectively.

Referring now to FIG. 2C, a diagram showing layout and schematic views of a routing guide according to an embodiment of the present invention is indicated by general reference characters **280** and **282**, respectively. Layout view **280** shows a routing for a signal path with ports A, B, and C. Such “ports” may be routing termination points, which may include any designations for subsequent signal connections, as intended for hierarchical layout block arrangements, for example. The routing includes a branch due to the splitter type routing guide, as shown. The “branching” or “splitting” can occur prior to or coincident with a placement of the splitter whereby a “net” is split into new nets and the associated connectivity is updated. A corresponding schematic model **282** may include a resistor on each branch of the signal routing. Alternatively, a schematic model may include only a single resistor with two ports. In any event, the routing guides are typically “sacrificial,” so the routing guides can be, and generally are, removed after signal path routing. In a particular automated flow, the routing guides can be removed after place-and-route, simulation, and/or timing optimization are completed. Such removing can be done with a “collapse all nets” type command.

Referring now to FIG. 3, a flow diagram showing a routing guide placement method according to an embodiment of the present invention is indicated by the general reference character **300**. The flow can begin in Start **302** and signal paths between logic blocks or the like can be determined (**304**). Of course, any appropriate signal path suitable for automated routing can be determined. Such a determination of an “interface” or signal path between logic blocks can be made by reference to a “netlist” file. Netlist files can be generated, for example, by a synthesizer based on a Hardware Description Language (HDL) representation of the logic functions of a circuit (which generally includes the logic blocks of the circuit), as will be discussed in more detail below with reference to FIG. 5.

In FIG. 3, the flow can continue with the identification of high fanout signal paths, such as clock signal paths (**306**). For example, signals or “nets” with at least three, four, or five connections to circuit blocks may be parsed from the netlist and identified as high fanout type signals. Splitters or other types of routing guides may be placed on such identified high fanout signal paths (**308**). The placement of routing guides can be performed automatically by an automatic placer and/or clock tree synthesis tool. Alternatively, routing guide placement can be done in an interactive or “manual” fashion. Typically, an initial routing guide (e.g., splitter) placement can be determined by timing considerations (e.g., by using a timing closure or clock tree synthesis tool). Such considerations may include results of timing checks as measured or otherwise determined at two or more of the circuit block connections. In this fashion, a timing, such as a signal path delay, can be substantially matched at the circuit blocks. Thus, the method may further include the step of checking the timing of the signal along the signal path, and placing the routing guide in a manner facilitating and/or enabling substantial matching of the timing. For example, the routing guide may be placed in a location enabling routing of signal path segments of substantially equal length between the routing guide (e.g., routing guides **214** and/or **216/218** in FIG. 2B)

and circuit blocks receiving the signal (e.g., logic blocks **204-210**) and/or other routing guides (e.g., routing guides **216/218**).

Once an initial splitter placement determination is made, that initial placement can be checked to ensure that it does not violate any routing restrictions (**310**). Such routing restrictions may include areas obstructed for routing, areas blocked off for placement and/or routing, or proximity too close to such areas. If the initial placement determination is acceptable (i.e., not subject to routing “restrictions”), the splitter can be placed (**312**) and the flow can complete in End **316**. If however, the initial placement determination is subject to a routing restriction, the splitter location can be adjusted (**314**) prior to the placement (**312**). The adjusting of the splitter location can include automatically determining a closest placement not subject to routing restrictions. Alternatively, a manual or interactive re-placement of the splitter can be employed. In this fashion, a routing guide can be placed so as to allow a signal path routing through the routing guide in order to substantially match a timing at two or more circuits or routing terminations.

Referring now to FIG. **4A**, a schematic diagram showing an exemplary circuit that may be used to demonstrate the present invention is indicated by the general reference character **400**. This example shows a simple circuit structure using standard cells or gates to implement logic or other functions that is suitable for IC design. Such logic functions could include AND/NAND, OR/NOR, XOR/XNOR, INV, or flip-flops, as just a few examples. In practice, any circuit can be designed and treated as a “standard cell” for automatic placement and routing in a larger design. More commonly, a set of standard cells are provided and characterized for each design technology and are utilized in an “off-the-shelf” manner in a typical ASIC design flow.

In the example of FIG. **4A**, standard cell **402** can be a buffer stage receiving input CLK and outputting signal **404** for a connection to a plurality of other standard cells (e.g., standard cells **410** and **414**). Standard cells **410** and **414** can be “AND” type functions, each having a NAND-gate followed by an inverter. Standard cell **410** can receive signal **404** at input connection **408** as well as CLK_EN at the other NAND-gate input. Standard cell **414** can similarly receive signal **404** at input **412** as well as CLK_EN, for example. Embodiments of the present invention can be used to optimize a timing or substantially match a timing delay to different circuit block locations. Consistent with such embodiments, signal path splitter **406** can be placed to guide the routing of signal path **404**. Further, a simulation of circuit **400** can be done to verify and/or further optimize any critical circuit timings.

Referring now to FIG. **4B**, an exemplary timing diagram for the circuit of FIG. **4A** is shown and indicated by the general reference character **450**. Such a timing diagram can be a waveform representation of a VERILOG simulation result, such as a Value Change Data (VCD) file, for example. Alternatively, another simulator, such as a SPICE-based simulator, may be used to obtain more detailed timing results. In FIG. **4B**, the waveforms are shown and labeled per their corresponding circuit “probes” in the circuit of FIG. **4A**. Clock signal CLK can be any type of oscillating signal and may go high (i.e., transition from “0” to “1”) and go low (i.e., transition from “1” to “0”) in alternating cycles. Waveform **406**, the output of a standard cell buffer stage, may be a slight delay of CLK. Waveform **408** can be a further delayed version of waveform **406** to reflect signal path and/or associated segment routing delay (e.g., $D1+D2$), as measured at signal transition midpoints, for example. Similarly, waveform **412** can be a delayed version of waveform **406** to reflect a signal

path and/or associated segment routing delay (e.g., $D1+D2$), as also measured at signal transition midpoints. As indicated in FIGS. **4A** and **4B**, a timing of a signal may be substantially matched (i.e., both see a delay of $D1+D2$) by the use of routing guides according to embodiments of the present invention.

Of course, as one skilled in the art will recognize, embodiments of the present invention are also applicable to analog, ternary, or other non-digital circuits. As one example, “small-signal” circuits, either alone or embedded within a larger chip or PCB may employ embodiments of the present invention. In general, embodiments of the present invention can be used in the routing of signal paths between circuit blocks or other routing termination points having interface signals that change states. Further, such state changes suitable for a “matched timing” determination may be of any type (e.g., analog, digital, etc.) recognizable by the interfacing or surrounding circuitry.

In this fashion, timing or other circuit performance “mismatches” due to signal path routing can be reduced or minimized according to embodiments of the present invention.

While the exemplary circuit block arrangements discussed above generally show the routing of signal paths between circuit blocks, these illustrations should not be considered limiting. As one skilled in the art will recognize, such routing may be accomplished between any three or more designated points and embodiments of the present invention are equally adaptable to such applications.

Referring now to FIG. **5**, a box diagram showing a synthesis flow adapted for use with embodiments of the present invention is indicated by the general reference character **500**.

Box **516** shows elements adapted for use in accordance with embodiments of the present invention. The remaining boxes in FIG. **5** represent a conventional synthesis flow. Inputs to Synthesis **508** typically include Constraints and Parameters **502**, Design Description (HDL) **504**, and Technology Library **506**. Constraints and Parameters **502** may include physical expectations of the design, such as the circuit operating speed and/or the circuit layout area. Design Description (HDL) **504** can be a VERILOG HDL (VHDL) description of the logic operation(s) for synthesis. Technology Library **506** may contain a functional description as well as other information, such as may be related to the area and speed of all standard cells in a given process technology. For example, Technology Library **506** may be specific to a technology generation (e.g., 0.13 micron technology), a company (e.g., TSMC), and a process type (e.g., CMOS; eight-level metal; fast/normal/slow lot variation).

Outputs from Synthesis **508** may include Schematics **510**, Netlist **512**, and Reports **514**. Schematics **510** can be schematic representations of the synthesized functions of Design Description (HDL) **504**. Netlist **512** can be a text file description of a physical connection of components, such as standard cells, and can include a description of the various circuit blocks in the design and signal paths between the circuit blocks. Reports **514** can include speed and area data associated with results of Synthesis **508**.

As discussed above, a netlist representation (e.g., Netlist **512**) may be used for circuit block placement and signal path determination. Accordingly, Block Placement **518** can receive Netlist **512** and provide input to Splitter Placement **520**. For example, information about the location of circuit blocks coupled to high fanout signal paths can be included in the input to Splitter Placement **520**. Of course, as one skilled in the art will recognize, Block Placement **518** and Splitter Placement **520** can substantially occur in the same automated step, such as by using an automated placement tool. Route

Signals **522** can receive information for route signal guidance from Splitter Placement **520** so as to make optimized signal path routes based on the positions of the splitters. Finally, Collapse Nets **524** can include removal of all routing guides.

In this fashion, a conventional ASIC type design flow including synthesis can be adapted for routing of signal paths between standard cells in accordance with embodiments of the present invention.

Further examples of suitable systems, tools and/or methods in which the present invention is generally applicable include those described in, e.g., U.S. Pat. Nos. 6,080,201 and 5,798,936, the relevant portions of which are each incorporated herein by reference, and those commercially available from place-and-route software vendors such as Cadence Design Systems (e.g., the SILICON ENSEMBLE™, SILICON ENSEMBLE-PKST™, FIRST ENCOUNTER™, and NANO ENCOUNTER™ tools), Silicon Valley Research, Inc. (e.g., the QIC/APR™, GARDST™, SCT™ and FLOORPLACER™ tools), Synopsys (e.g., the CHIP ARCHITECT™, DESIGN COMPILER™, and FLOORPLAN COMPILER™ tools) and Mentor Graphics (e.g., the AUTO-CELLS™ tool).

Thus, embodiments of the present invention can advantageously improve signal timing for high fanout signal paths between circuit blocks in an automated place-and-route flow. Embodiments of the present invention are suitable for the automated routing of signal paths between circuit blocks within an integrated circuit (IC) and/or routing between ICs or components on a board, such as a printed circuit board (PCB).

The foregoing descriptions of specific embodiments of the present invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed, and obviously many modifications and variations are possible in light of the above teaching. The embodiments were chosen and described in order to best explain the principles of the invention and its practical application, to thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated. It is intended that the scope of the invention be defined by the claims appended hereto and their equivalents.

What is claimed is:

1. A method of routing, comprising:

- a) determining a signal path between at least three circuit blocks;
- b) automatically placing a routing guide along the signal path;
- c) routing said signal path through said routing guide such that a timing of a signal along said signal path at two or more of said at least three circuit blocks is substantially matched; and
- d) after routing said signal path, removing said routing guide.

2. The method of claim 1, wherein determining said signal path occurs prior to placing said routing guide.

3. The method of claim 1, wherein determining said signal path includes matching said signal path to a corresponding one of a plurality of nets in a netlist describing said at least three circuit blocks.

4. The method of claim 1, wherein at least one of said at least three circuit blocks includes a standard cell configured to implement a logic or timing function.

5. The method of claim 1, wherein at least one of said at least three circuit blocks includes a routing termination.

6. The method of claim 1, wherein said routing guide includes a splitter configured to branch said signal path into at least two segments.

7. The method of claim 1, wherein placing said routing guide includes adjusting an initial placement determination in response to a routing restriction on said initial placement.

8. The method of claim 1, further including checking said timing after placing said routing guide and prior to removing said routing guide.

9. The method of claim 8, wherein said routing guide is placed in a manner facilitating and/or enabling substantial matching of said timing.

10. The method of claim 1, wherein said timing includes a delay of said signal path.

11. The method of claim 1, wherein said routing guide includes a delay indicator.

12. The method of claim 11, wherein said delay indicator comprises sufficient signal path routing length to substantially match a signal path delay in another signal path.

13. The method of claim 1, further including synthesizing a circuit implementation in response to a hardware description, said hardware description including said at least three circuit blocks and said signal path.

14. The method of claim 1, wherein each of said at least three circuit blocks includes an integrated circuit or component.

15. A computer-readable medium containing a non-transitory computer-executable set of instructions, the instructions adapted to perform the method of claim 1.

16. The computer-readable medium of claim 15, further comprising at least one instruction for selecting said routing guide.

17. The computer-readable medium of claim 15, wherein determining said signal path includes matching said signal path to a corresponding one of a plurality of nets in a netlist describing said at least three circuit blocks.

18. The computer-readable medium of claim 15, wherein determining said signal path occurs prior to the step of placing said routing guide.

19. The computer-readable medium of claim 15, wherein at least one of said at least three circuit blocks includes a standard cell configured to implement a logic or timing function.

20. The computer-readable medium of claim 15, wherein at least one of said at least three circuit blocks includes a routing termination.

21. The computer-readable medium of claim 15, wherein said routing guide includes a splitter configured to branch said signal path into at least two segments.

22. The computer-readable medium of claim 15, further including at least one instruction for synthesizing a circuit implementation in response to a hardware description, said hardware description including said at least three circuit blocks and nets corresponding to the signal path.

23. The computer-readable medium of claim 22, further including at least one instruction to include a resistor on each branch of said signal path.

24. The computer-readable medium of claim 22, wherein said routing guide is removed by at least one command to collapse all nets.

25. The computer-readable medium of claim 15, wherein each of said at least three circuit blocks includes an integrated circuit or component.

26. The computer-readable medium of claim 15, further comprising at least one instruction for adjusting an initial placement determination in response to a routing restriction on said initial placement.

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27. The computer-readable medium of claim 15, wherein said timing includes a delay of said signal path.

28. The computer-readable medium of claim 15, wherein said routing guide includes a delay indicator.

29. The computer-readable medium of claim 28, wherein said delay indicator comprises sufficient signal path routing length to substantially match a signal path delay in another signal path.

30. The computer-readable medium of claim 15, further comprising at least one instruction to check said timing after placing said routing guide and prior to removing said routing guide.

31. The computer-readable medium of claim 30, further comprising at least one instruction to place said routing guide in a manner facilitating and/or enabling substantial matching of said timing.

32. A computer system comprising the computer-readable medium of claim 15, configured to execute the computer-readable set of instructions.

33. The method of claim 1, wherein said routing guide comprises a splitter having a first input and first and second outputs, said splitter having a position such that the timing of said signal along first and second segments of said signal path substantially matches a timing of said signal along first and third segments of said signal path, wherein said first segment of said signal path has a first terminal at a first one of said at least three circuit blocks and a second terminal at said first input of said splitter, said second segment of said signal path has a first terminal at a second one of said at least three circuit blocks and a second terminal at said first output of said splitter, and said third segment of said signal path has a first terminal at a third one of said at least three circuit blocks and a second terminal at said second output of said splitter.

34. The method of claim 1, wherein said signal path is a clock signal path.

35. A method of connecting circuit blocks, comprising:

- a) determining a plurality of signal paths interfacing said circuit blocks;
- b) determining whether any of said plurality of signal paths are high fanout signal paths;
- c) placing a routing guide for an identified high fanout signal path using a computer or data processing system;
- d) routing said identified high fanout signal path through said routing guide such that a timing of a signal along said signal path at two or more of said circuit blocks is substantially matched; and
- e) removing said routing guide.

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36. The method of claim 35, wherein determining said plurality of signal paths interfacing said circuit blocks includes accessing a netlist created by a synthesizer in response to a hardware description, said hardware description including said circuit blocks and nets corresponding to said signal path.

37. The method of claim 35, wherein determining whether any of said plurality of signal paths are high fanout signal paths includes determining signal paths having connections to at least three of said circuit blocks.

38. The method of claim 35, further including selecting said routing guide from the group consisting of a splitter and a delay indicator.

39. The method of claim 35, wherein at least one of said circuit blocks includes a standard cell configured to implement a logic or timing function.

40. The method of claim 35, wherein at least one of said circuit blocks includes a routing termination.

41. The method of claim 35, wherein said routing guide includes a splitter configured to branch said identified high fanout signal path into at least two segments.

42. The method of claim 35, wherein each of said circuit blocks includes an integrated circuit or component.

43. The method of claim 35, further including placing said circuit blocks.

44. The method of claim 35, wherein said timing includes a delay of said identified high fanout signal path.

45. The method of claim 35, wherein said routing guide includes a delay indicator.

46. The method of claim 45, wherein said delay indicator comprises sufficient signal path routing length to substantially match a signal path delay in another signal path.

47. The method of claim 35, wherein a position of said routing guide is automatically determined.

48. The method of claim 35, further including checking said timing after placing said routing guide and prior to removing said routing guide.

49. The method of claim 48, wherein said routing guide is placed in a manner facilitating and/or enabling substantial matching of said timing.

50. A computer-readable medium containing a non-transitory computer-executable set of instructions, the instructions adapted to perform the method of claim 34.

51. A computer system comprising the computer-readable medium of claim 50, configured to execute the computer-executable set of instructions.

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